A Pedestrian Traffic Model for Town Centers

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EXTENSIVE downtown renewal characterizes contemporary Sweden. Existing town centers often have a street system dating from the eighteenth and nineteenth centuries, while most development is from the nineteenth and the early part of the twentieth century. The development of out-of-town shopping centers during the last decade has led to a consequent outward movement of retailing functions from the central areas. One reason for this outward movement has been the deteriorating traffic environment in town centers. In order to meet this problem many Swedish town centers are now being redeveloped primarily with pedestrian traffic in mind, and this has led, among other things, to the need to develop models to calculate present and future pedestrian traffic.

Örebro, with 91,000 inhabitants, is Sweden's fifth largest town. Its center is being redeveloped to give priority to pedestrian traffic, the present planning work having been presented in the form of a Central Area Action Plan during 1971. As a result of earlier studies of the basic structure plan for the town center, the town of Örebro commissioned the construction of a pedestrian traffic model and a 1980 forecast of pedestrian traffic in the town center.[1] The model was to represent conditions during average peak shopping periods, defined here as the thirtieth to fiftieth busiest hour per year. (This is represented by 12 midday Saturdays during spring and autumn. The highest peak period falls during a few hours during the Christmas period, when sales and customer frequency are double the average for peak shopping periods.) Additionally, the model was to give a suitably detailed description of pedestrian traffic for use with synoptic town center planning, while at the same time being relatively easy to use and within reasonable cost limits.

THE ÖREBRO TOWN CENTER

In spite of the development of out-of-town shopping centers, the majority of larger Swedish town centers can be expected, and are being planned, to retain their dominant retailing interests. As a result, retailing functions together with their requisite parking needs will demand an increasing share of the available net land area in the town center. For Örebro this means that the gross floor area for retailing, expressed in relation to the total available site area for these functions, will increase from approximately 0.2 today to around 0.6 by the year 2000. If parking is included, the corresponding figures would be approximately 0.5 and 1.4. The density of all development (expressed as net floor area in relation to the area of each block) is approximately 1.0 today, and is expected to rise to 1.8 between 1980 and 1990. As in other Swedish towns the predominate means of transport to the shops in the town center during peak shopping periods is by car. Approximately 60 percent of the total number of trips to the town center have retailing functions as their primary or secondary objective.

The active retailing section of Örebro town center is today approximately 1,300 meters long, corresponding to about ten blocks, and between 100–200 meters, or two to three blocks wide. Figure 2 shows how the floor area for retailing and other commercial service functions and how the major parking areas are distributed in the town center today. It should be noted that Figure 2 expresses the floor area for retailing functions in effective net floor area; i.e., the actual floor area is reduced in relation to total annual turnover so that it corresponds to the rates of turnover per square meter to be expected in newly established shops today. The actual floor space area for retailing and other commercial service functions was, in 1969, approximately 120,000 square meters. Feasibility studies showed that it would be possible to increase this area to approximately 180,000 square meters by 1980, as well as to reserve space for the requisite extra parking that would be needed. It was recognized at the same time, nonetheless, that this total increase was of sufficient magnitude to present several problems in future planning of the central area. The basic design principle adopted for the central area, which today consists of shops on either side of the main thoroughfare (Drottninggatan-Storgatan), was to allow future retail development to extend at right angles to it along selected streets which would form pedestrian malls. New larger retailing and parking facilities located along these malls would form "magnets" of attraction, while existing retailing units would remain in prime locations. The main traffic thoroughfare (Drottninggatan-Storgatan) would be reserved solely for public transport, taxis, etc.; all other vehicular traffic being directed to the city ring road system. Drottninggatan-Storgatan would retain its important function as a pedestrian thoroughfare. These proposals are summarized in Figure 3.

The object of the pedestrian traffic model was to illustrate the effects of these proposed changes on the physical structure of the central area. Problems to be considered were the effect of new retail locations upon existing retail units in terms of changes to the "center of gravity" of the present retailing area; the effects of increased walking distances and the increased area given over to pedestrian use; the development of quantitative criteria for the assessment of future design requirements for pedestrian areas in terms of their expected capacity and required furnishing; and finally, the quantification of probable future conflict situations between vehicular and pedestrian traffic, particularly with regard to the public transport route crossing the proposed pedestrian malls.

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GENERAL METHODOLOGY

The work on the pedestrian traffic model and forecast progressed as follows. After a hypothetical traffic generation model was established, a survey was carried out during May and June 1969 of particular aspects of pedestrian traffic in the southern town-center area of Örebro. This survey information served as the basic material for the determination of a traffic generation model. Final construction and testing of the model and its parameters was carried out with the aid of a computer. The model (now in the form of a computer program) and its variables were adjusted to incorporate the likely conditions for 1980, after which a forecast was made of pedestrian traffic for the whole town-center area of Örebro.

The Hypothetical Model

Since a conventionally constructed, gravitational traffic generation model would require an accurate and detailed description of pedestrian traffic behavior (for example, in terms of action sequences and resistance values), it was felt that the magnitude of the difficulties, as well as time and cost factors, necessitated the choice of other methods. The hypothetical model which resulted was based upon the assumption that a predominant proportion of pedestrian movement in medium-sized town centers can be characterized by the accumulation of pedestrians around interesting objects, in this particular case (during average

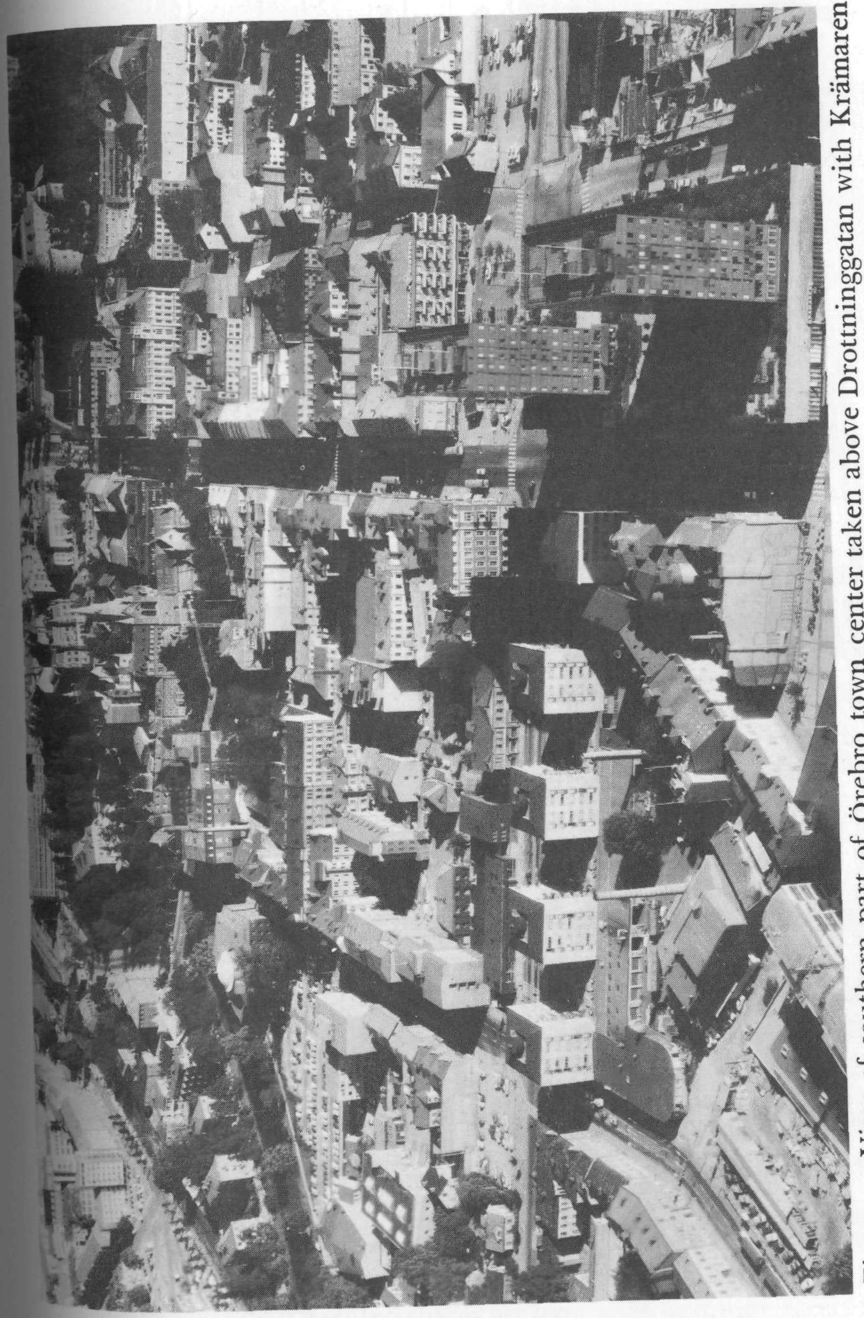

Figure 1. View of southern part of Örebro town center taken above Drottninggatan with Krämaren Department store in foreground. Note Örebro castle in top right hand corner. Photograph by courtesy of AB Flygtrafik, Dals-Långed, Sweden

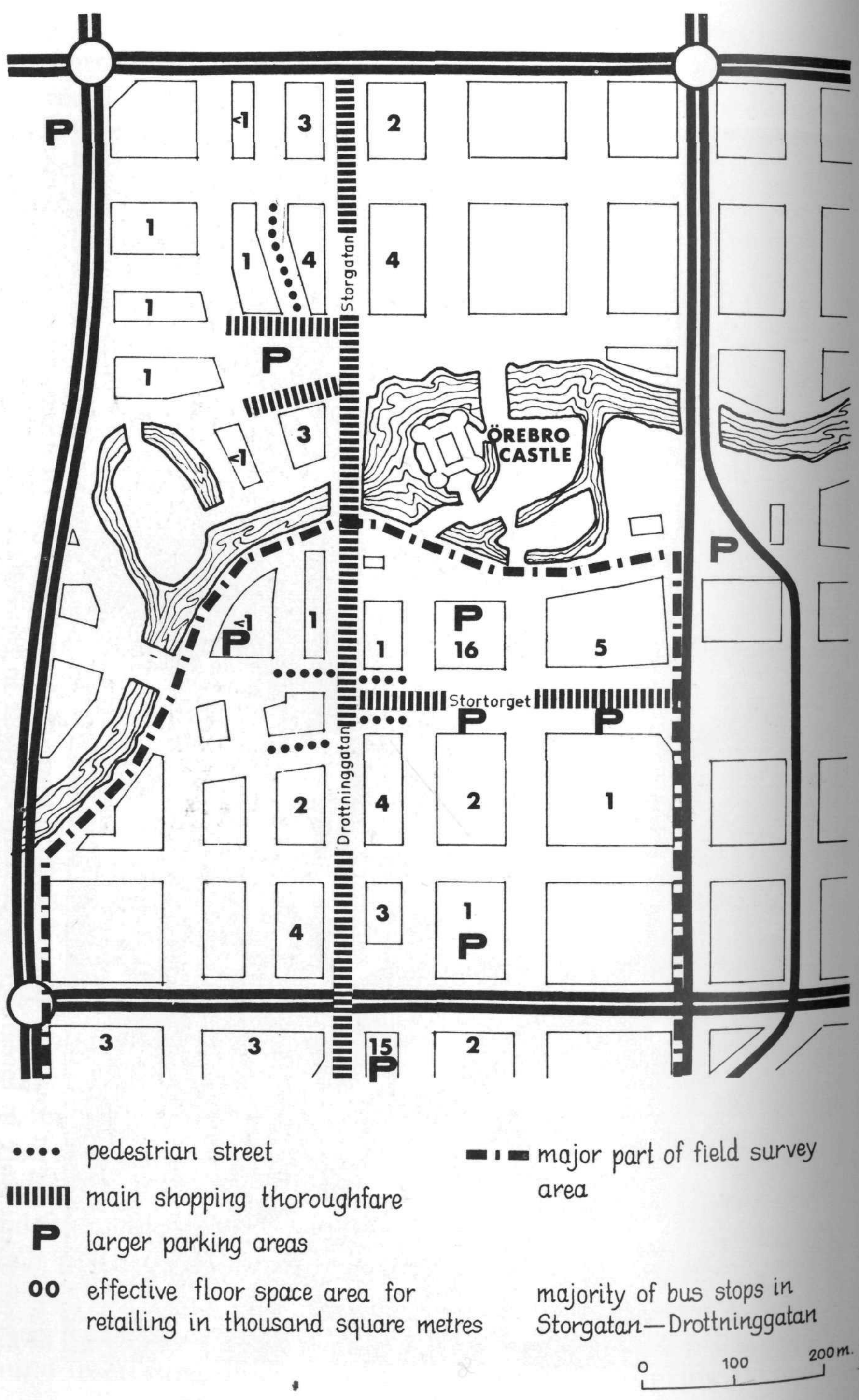
P
ÖREBRO CASTLE
Storgatan
Drottninggatan
Stortorget
16
15
5
4
3
2
1
-1
pedestrian street
main shopping thoroughfare
larger parking areas
00 effective floor space area for retailing in thousand square metres
major part of field survey area
majority of bus stops in Storgatan—Drottninggatan
0
100
200m.

Figure 2. The Örebro town center, 1969

peak Saturday shopping periods or their equivalent) around floor space area for retailing and other commercial service activities. The model does not cover the chain of visit sequences between different objects. Instead, these are described in a simpler form as the addition of accumulated persons around interesting objects in such a way that the addition is proportional to the object's degree of centrality in the town center. Other movements included in the model are goal-oriented movement from parking areas to shops or shopping streets, movements originating outside the town center to the town center, etc. The constuction was first tested manually against the survey material, and then with the aid of regression analysis. The manual tests alone showed that the model accurately described the density distribution of pedestrian traffic in the southern part of the town center in Örebro during the 1969 dimensioning period.

In order to make the analysis and calculations in a systematic way, the town center was divided into a matrix system whereby each matrix corresponded to a street length between blocks. Shops, or rather figures of effective net floor area, were related to that matrix which included the shop's main entrance. All data, including the resulting number of pedestrians, were recorded per matrix. The pedestrian traffic generation model representing the situation during the dimensioning period was given the following basic construction, where *i* represents the matrix or street length between blocks.

$$T_i = a\cdot Y_i + b\cdot P_i + c\cdot B_i + d\cdot C_i + e\cdot U_i + f\cdot G_i + g\cdot S_i + h\cdot P_{ki} + k$$

where:

T_i = the simultaneous number of pedestrians in matrix i

a = the simultaneous number of pedestrians accumulated around retailing and other commercial service activities during the dimensioning period

Y_i = effective net floor space area in square meters for retailing or other commercial service activities; effective net floor area represents total annual turnover expressed as an optimal floor area space

b = simultaneous number of pedestrians accumulated around parking areas for long-term parking

P_i = number of parking spaces for long-term parking

c = simultaneous number of pedestrians accumulated around bus stops
B_i = number of bus routes (stopping)
d = total pedestrian accumulation addition on the basis of centrality in town center
C_i = proportion of d in matrix i, or centrality of matrix i
e = proportion of pedestrian traffic crossing the boundary of the central area, expressed as goal-oriented movement toward the central area
U_i = number of pedestrians crossing the central area boundary
f = simultaneous number of pedestrians accumulated around street stalls
G_i = number of street stalls or kiosks
g = simultaneous number of pedestrians accumulated around public seating places
S_i = number of public seating places
h = simultaneous number of accumulated pedestrians around short-term parking spaces
P_{ki} = number of public parking spaces for short-term parking
k = constant (intercept); number of pedestrians in matrix i that, on the basis of the model chosen, cannot be directly related to any one of the descriptive variables

The model described above was easier to use and considerably less expensive than a pure gravitation model, since the requisite data were of simpler form. As is shown later considerable modifications can be made to the model (for example, $T_i = aY_i$) where simpler, approximative manual calculations are required. Similarly variables G_i and S_i do not need to be included in the forecast model. They were included here because they can have relatively high disturbance effects upon certain matrices in the regression analysis. Other variables that could be included in the model include net floor space areas for functions other than retailing, as well as environmental values. These factors have, however, relatively little importance during the dimensioning period. The constant (intercept) was assigned after special analysis of the other coefficients. The hypothetical model also included numerical values for the coefficients.

Survey of Pedestrian Traffic in Southern Town-Center Area

A field study in May 1969 of pedestrian traffic in all the streets in the southern part of Örebro's town center provided the basic information for final determination and calibration of the hypothetical model. The major parameter, the number of pedestrians per street length or individual matrix, was observed manually together with observations of pedestrian speeds and flows. The observations, totaling 21 hours, were carried out on Wednesday, Friday, Saturday, and Sunday during different times of the day for two consecutive weeks at the end of May and beginning of June. Figure 4 shows the number of pedestrians in the southern part of the town center during the average peak shopping period, according to the field survey. It is apparent from comparison of Figures 2 and 4 that pedestrians accumulate in conjunction with the larger retailing units.

Result I—Pedestrian Traffic Generation Model, Southern Part of Örebro Center, 1969

The coefficients in the hypothetical model were calculated partly on the basis of manual adjustment and partly with the help of regression analysis by computer. The regression coefficients so obtained were further adjusted to eliminate certain incongruous effects from a physical planning point of view.

The values for 1969 of the descriptive variables Y_i, P_i, etc., in the model have been obtained directly from different surveys except for C_i and U_i, which were obtained by regression analysis. A list of the sum values for the southern part of the town center for 1969 is given below.

Y_i = 49,000 square meters (effective net floor space)
P_i = 640 parking spaces (long-term parking)
B_i = 70 bus stops times number of bus routes
C_i = 0.8
U_i = 150 pedestrians
G_i = 25 street stalls or kiosks
S_i = 50 public seats
P_{ki} = 330 parking spaces (short-term parking)

Regression analysis of the survey data in the pedestrian traffic generation model resulted in evaluation of the independent descriptive variables influence on the dependent studied variables. The descriptive variables in this case were Y_i, P_i, etc., as listed above, while the studied variable was the number of pedestrians T_i. The regression method chosen was a multiple stepped regression which can be described as a curve adjustment method. Thus for a number of observations of pedestrian volumes, there was a group of descriptive data that was assumed to match the observed pedestrian traffic. Variations in pedestrian traffic were explained as far as possible by variations in the proposed variables, so that the coefficients in the adopted model could be calculated. In the regression analysis no regard was taken of causal relationships between the variables.

Variable C_i was specially constructed, four different submodels being tested. The following model gave the least deviation in the regression analysis and was accepted on that basis.

$$C_i = \frac{\sum_j \frac{Y_i Y_j}{(a_{ij})^n}}{\sum_i \sum_j \frac{Y_i Y_j}{(a_{ij})^n}}$$

where C_i = the relative centrality of matrix i
a = walking distance between matrix i and matrix j
Y_j = effective net floor-space area for retailing and other commercial service activities in matrix j
n = distance factor exponent

As in other centrality models, different combinations of independent variables were tested by regression analysis. For both the main model and the submodel the chosen alternatives were those that showed the greatest degree of coordinated variation and best fitted the observed pedestrian traffic. For the main model a complete combination of variables as given above proved the most suitable.

The values concerning conditions in 1969 of the regression coefficients a, b, etc., in the model were obtained by regression analysis. Over and above the variables obtained directly from the analysis, further adjusted values were obtained after assignment of the intercept to the coefficients. The adjusted values (see Table I), were given to two combinations (1) where the whole intercept was assigned to the coefficients and (2) where the intercept was retained except for that part necessary to adjust coefficient c. The second combination was chosen.

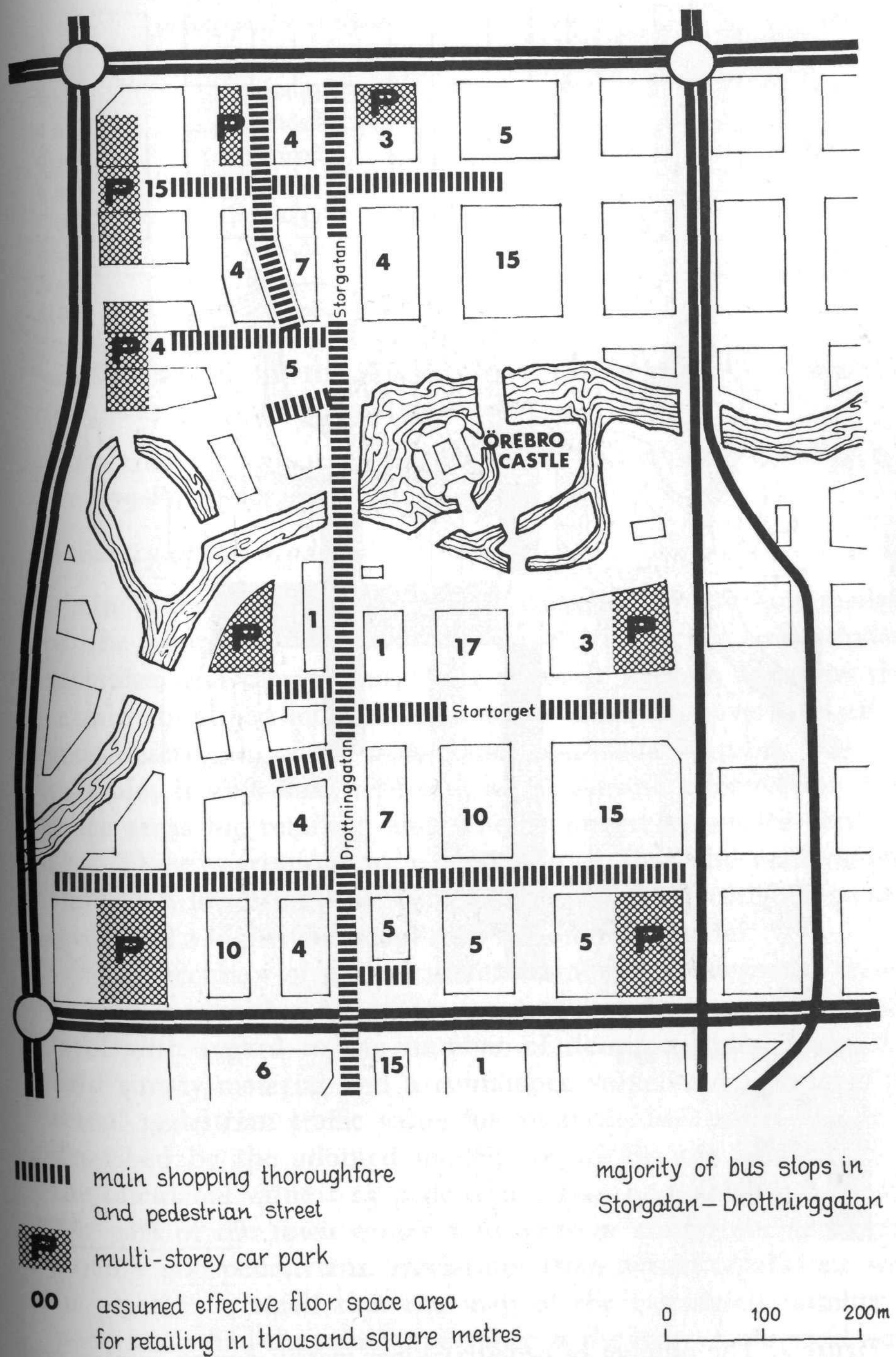

Figure 3. The Örebro town center, 1980

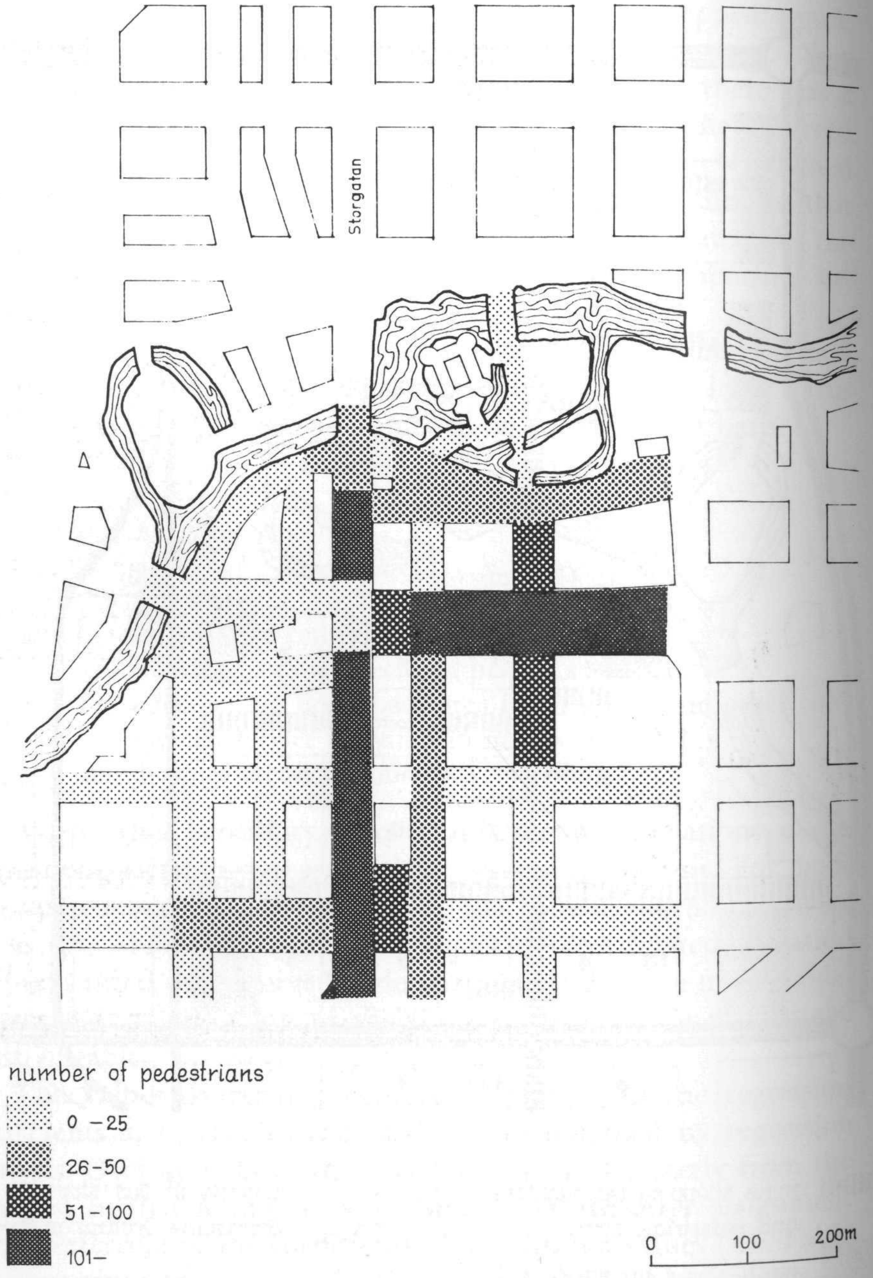

Figure 4. The number of pedestrians per matrix during average peak shopping period, southern part of town center, 1969

TABLE I—VALUES ASSIGNED TO COEFFICIENTS, 1969

	Direct Value According to Regression Analysis	*Adjusted Value (1)*	*Adjusted Value (2)*
a =	0.00849	0.011	0.0085
b =	0.10849	0.11	0.11
c =	−0.22826	1.0	1.0
d =	872.83008	980.0	870.0
e =	0.96244	1.0	1.0
f =	7.00437	7.0	7.0
g =	0.42582	0.43	0.43
h =	0.79417	0.79	0.79
k =	4.18270	0	3.2

The model, for the southern part of Örebro's town center in 1969, was given the following form.

$$T_i = 0.0085\ Y_i + 0.11\ P_i + 1.0\ B_i + 870\ C_i + 1.0\ U_i + 7.0\ G_i + 0.43\ S_i + 0.79\ P_{ki} + 3.2$$

Accuracy of the Model

In order to test the method's sensitivity, regression analysis of the simplified models, i.e., those with fewer independent variables, was carried out. As a result it became apparent that certain simplified models, such as $T_i = 0.024\ Y_i$, gave a relatively good description of the main pedestrian traffic features. The best variables in this case were centrality (C_i) and effective net floor space areas for retailing and other commercial service activities (Y_i). These regressions were less accurate than the main model, yielding a lower multiple correlation coefficient, a higher median error, and a higher intercept than the adopted model.

The accuracy of the calculated number of pedestrians should be expressed within a confidence interval at the chosen confidence level with regard to the number of determinations. Using the field survey material and a confidence value of 95 percent, the actual pedestrian traffic value for an individual street length, as described by the adopted model, lay within the boundaries of the calculated value ± 25 pedestrians. For the whole of the southern part of the town center a 95 percent confidence level gave 2,060 ± 200 pedestrians. Deviations from actual conditions were in practice so small that the map of the calculated number of pedestrians had the same appearance as the map of observed number of pedestrians. Figure 5 shows the close correlation between the observed and calculated number of pedestrians per matrix for the shopping thoroughfare Drottninggatan-Stortorget between two department stores. The model was, therefore, regarded as giving a good description of pedestrian traffic density during the dimensioning period in 1969. In addition, the model gave some indication of the varying characteristics of pedestrian traffic in different parts of the town center. Some adjustments would, however, be necessary to describe conditions during non-peak shopping periods, and new regression coefficients would have to be calculated.

Result II—Peak Shopping Period Pedestrian Forecast, Örebro town center, 1980

Use of the model for forecasting requires giving attention to changes in buying habits, future retailing structure, and the physical form of the town center. These changes may be incorporated in the model as adjusted coefficient and variable values. New variables, other than those suggested for 1969, can also be incorporated: for example, variables that describe environmental values or movements to and from work. Forecasting techniques are often fraught with the difficulty of choosing new variables. In this case it was considered likely that new variables played a less important role during peak shopping periods, since the pedestrian traffic is narrowly defined as comprising a majority of shoppers. In this way the data necessary to forecast pedestrian traffic in 1980 were of a relatively simple nature compared with the data requirements for more conventional traffic forecasts. Modification of the model to represent conditions during average peak shopping periods in 1980 did require new values for coefficients *a*, *b*, *c*, etc., as follows.

$a = 0.0068$ The value is lower than that for 1969 because of increased sales per person (with consequent reduction in pedestrians per unit of floor area), increased size of retailing units, and increased length of stay in the town center. In the sensitivity analysis for different values of *a*, that is, *a* for 1980 = 0.6 or 0.8 or 1.0 times *a* for 1969, it was shown that sensitivity was slight and that $a = 0.0068$ was the most probable value for 1980.

$b = 0.11$ The 1969 value for longer term parking is assumed applicable for all parking in 1980, which will be accommodated in multistory parking garages with main pedestrian entrances to pedestrian streets. In the sensitivity analysis *b* was also given values of 0.07 and 0.09.

$c = 2.0$ Increased trip frequency and usage give higher values for 1980 than 1969; how much higher depends on future public transport policy. A reasonable assumption was to double the value.

$d = 1{,}800$ The 1980 value should be raised at the same rate as the increase in floor area, modified by a decision on the relationship between coefficients *a* and *d*. The changes in conditions between 1969 and 1980 that affect the relation d/a are increased size of retailing units, increased retail area per matrix, increased total area for the town center, and an increase in the proportion of sequences of visits by car or by other transport methods. Increased size of retailing unit means a lower number per matrix, and an increase in the sequence of visits between matrices and, therefore, an increased value of relation d/a. However, an increase in retail areas per matrix can mean more retailing units and, therefore, a reduced value for the relationship. Similarly, an increase in size of the town center as a whole will increase d/a, while an increase in the proportion of visit sequences by car or other transport methods will reduce the ratio. Weighing all these factors together it seems reasonable to assume that the relationship d/a will be the same in 1980 as it was in 1969.

$e = 1.0$ Value of incoming pedestrians to town center adjusted manually.

$f = 7.0$ No change appeared necessary.

$g = 0.4$ No change, as in *f* above.

$h = 0$ All short-term parking spaces on street curb sides assumed eliminated.

$k = 3.2$ Same value as for 1969. A slightly lower value could be argued, since Swedish town centers in the future appear more likely to be dominated by floor-space area for retailing than at present.

A sensitivity analysis of different coefficient values showed that the value T_i obtained was relatively unaffected by reasonable changes to the coefficient values. The different alternative groups of coefficients varied the calculated number of pedestrians per street length by ± 10 percent, though in some cases variations of ± 20 percent were noted. For the town center as a whole, the various alternatives were relatively similar.

In addition, an independent forecast was made for the expected future total of pedestrians in the town center in 1980. In this forecast, allowance was made for changes in population structure, retailing structure, and travel habits in the region. The resulting value of between 5,000 to 6,000 persons agreed relatively well with the value calculated in the pedestrian traffic model.

The Forecast Model

The new coefficients suggested for 1980 resulted in the following model for the whole of the town center during average peak shopping periods:

$$T_i = 0.0068\, Y_i + 0.11\, P_i + 2.0\, B_i + 1800\, C_i + 1.0\, U_i + (7.0\, G_i + 0.4\, S_i) + 3.2$$

The model was applied to one of the structure plan alternatives for Örebro town center, and the number of pedestrians per matrix as a result is shown in Figure 6. A completely different pattern can be seen when the total is compared with that for 1969, due to important changes in the physical structure of the central area.

The median error in the forecast gave an uncertainty of approximately ± 25 percent in each matrix. Further analysis showed, however, that the final result was relatively independent of reasonable variations in the values assigned to coefficients. It should be remembered, nevertheless, that for physical planning purposes individual matrices with high numbers of forecasted pedestrians may in practice diverge by as much as 50 percent from the actual values. For matrices with a low number of forecasted pedestrians (for example, between 0 and 30), divergencies

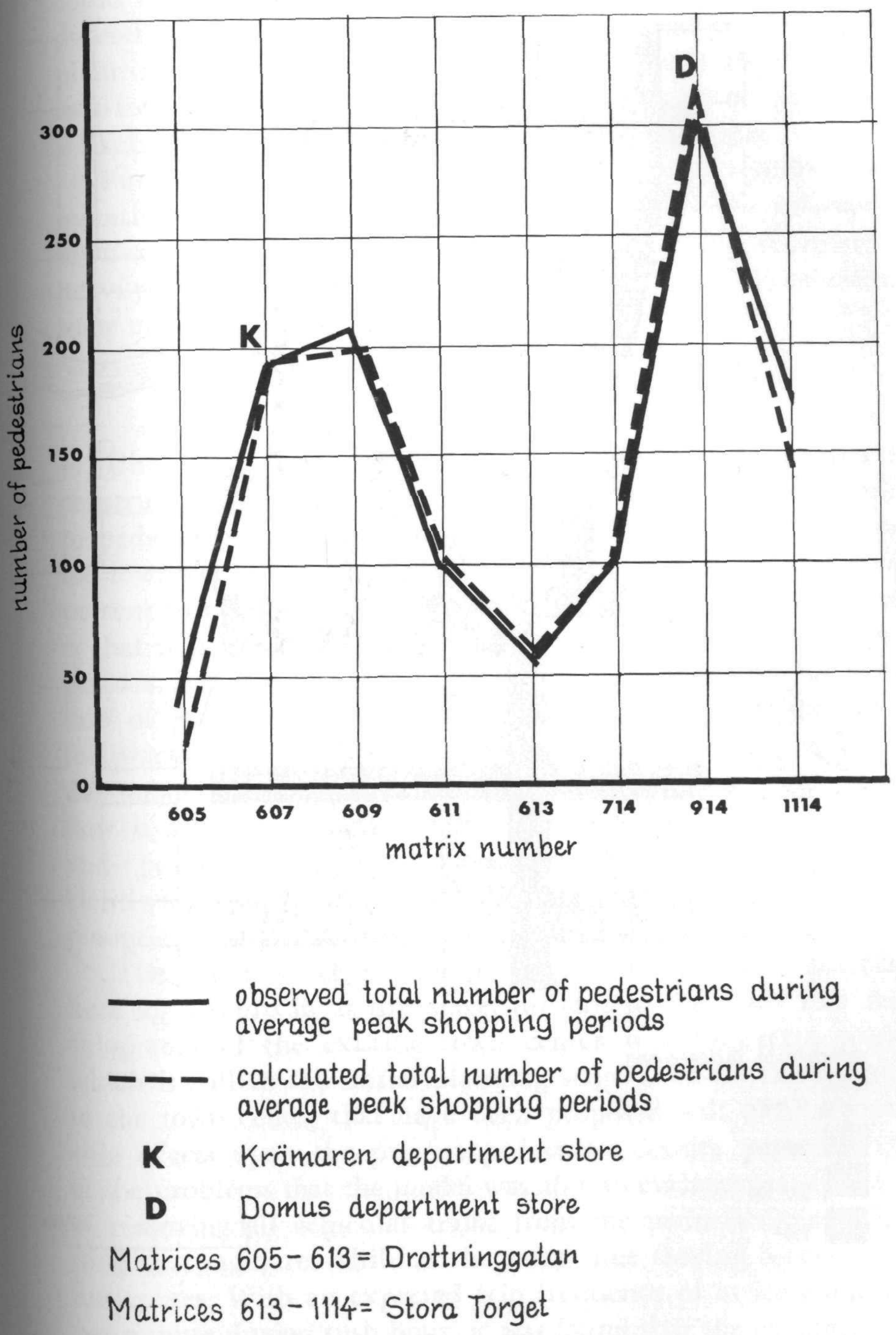

Figure 5. The number of pedestrians during peak shopping period along two selected streets, 1969

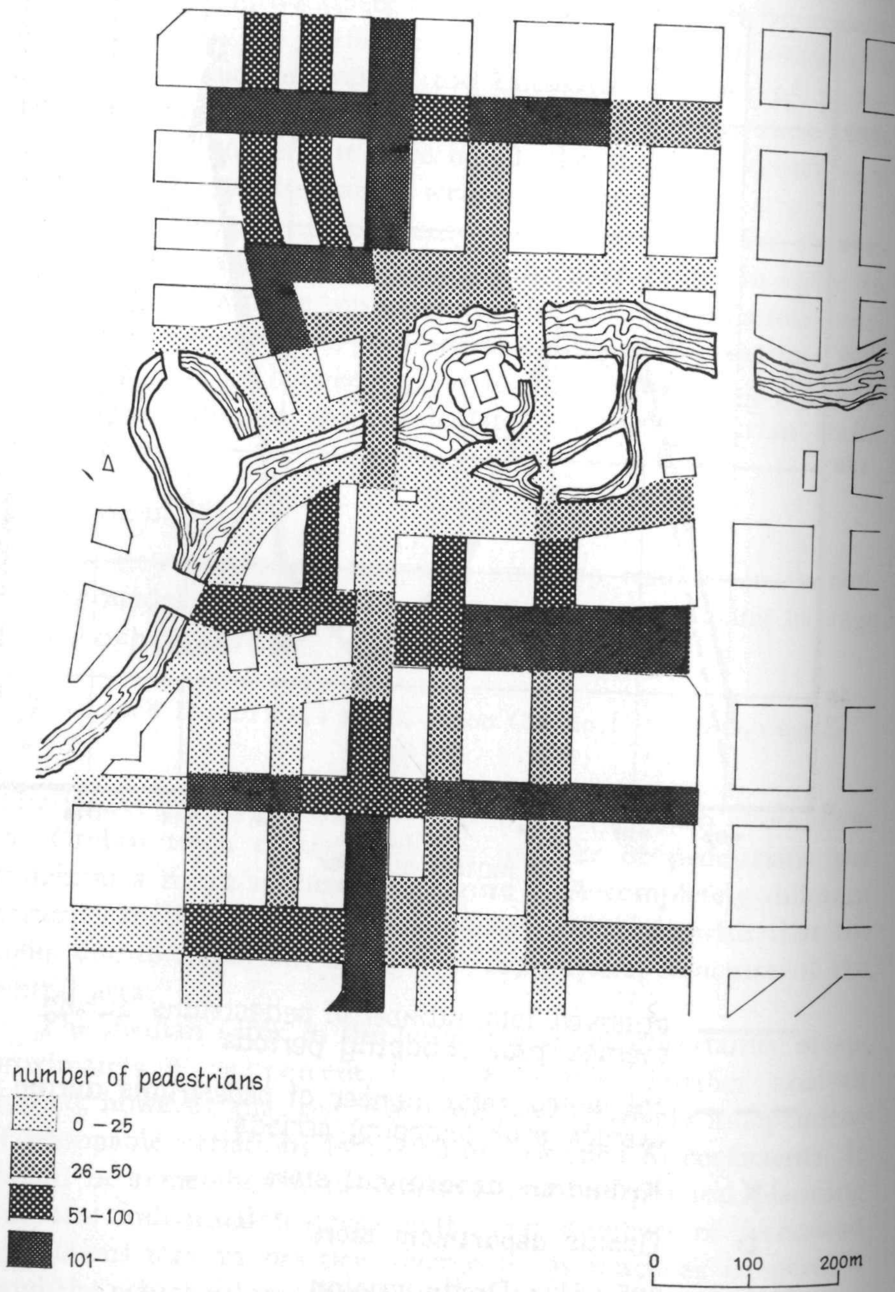

Figure 6. Calculated number of pedestrians per matrix during peak shopping period, 1980

could be of the order of several hundred percent, though such differences would be of little practical significance in physical planning terms. For continuous pedestrian areas of about four matrices the uncertainty in the total number of pedestrians is likely to be about half that of the individual matrices.

Further testing of the model in other town centers would quantify in what way the coefficient values vary in relation to town-center size and structure. Since the centrality submodel is heavily dependent on the physical structure of the town center, some modification may also be required.

CONCLUSION

Until more detailed and functionally more correct models are constructed, it is felt that the model described here is applicable to pedestrian traffic forecasts parallel with other traffic forecasts for town centers. It must be remembered that the model, in its present form, has a number of restrictions. The most important is that it is not calibrated for other than average peak shopping periods. But the average peak shopping period is, at least in the case of Swedish medium-sized towns, the dimensioning period for practically all pedestrian areas in town centers. Additionally, the model relates to pedestrian density, whereas pedestrian flow is of greater interest in evaluation of conflicting vehicular and pedestrian traffic. Nevertheless the model gives sufficiently accurate results, in its present application, to be of use in synoptic physical planning.

The actual value of the pedestrian traffic model described here for Örebro is, at this stage, difficult to evaluate. The redevelopment of the existing town center is a long-term project which is still in the initial planning stage. The physical changes to the town center that have been proposed will have considerable effects upon the present pedestrian density patterns. One of the problems that the model was able to evaluate was the effect of removing all vehicular traffic from the main (existing) shopping thoroughfare, while at the same time leaving access for all bus routes. With an expected trip frequency of at least one trip per minute during rush hour, it was found that the existing pavements (sidewalks) would need to be widened. Without the model's help the degree of conflict of the new plan situation with proposed pedestrian streets at right angles to the existing main shopping thoroughfare would have been difficult to evaluate. Similarly, the model provided a quantitative means of assessing proposed structure changes to the town center, in terms of changes to existing pedestrian density patterns.

The model has also been tested more recently in a smaller town center (Vänersborg, population 20,000) in combination with alternative locations of a new department store with a floor area of 10,000 square meters. Here it was essential to evaluate how far away from the existing highest pedestrian densities the store could be located without too severe a break in contact with existing pedestrian density patterns.

In order that a pedestrian traffic forecast of the sort described here can be advantageously used in physical planning, the consequences of different pedestrian traffic densities must first be clarified. This study did not cover these aspects and, as a result, only some self-explanatory correlations are put forward:

Proposed pedestrian streets with low pedestrian density (T_i) should be reexamined in terms of dimension and function. Few pedestrian streets need to be dimensioned on a capacity basis.

Pedestrian streets with high pedestrian density (T_i) should be designed to high standards with, for example, undersurface heating or partial or complete overroofing, and furnished with greenery, fountains, kiosks, rest corners, children's play areas, decorative arts, etc.

Pedestrian streets dominated by goal-oriented movement should be reexamined for capacity. Goal-oriented movement is described by variables P_i and U_i.

Sites alongside pedestrian areas dominated by movement variables Y_i or C_i (floor space areas for retailing or degree of centrality), or that have high values for these variables, should normally be regarded as good retail sites with high property values. The model thus suggests a new quantitative basis for the calculation of property values.

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